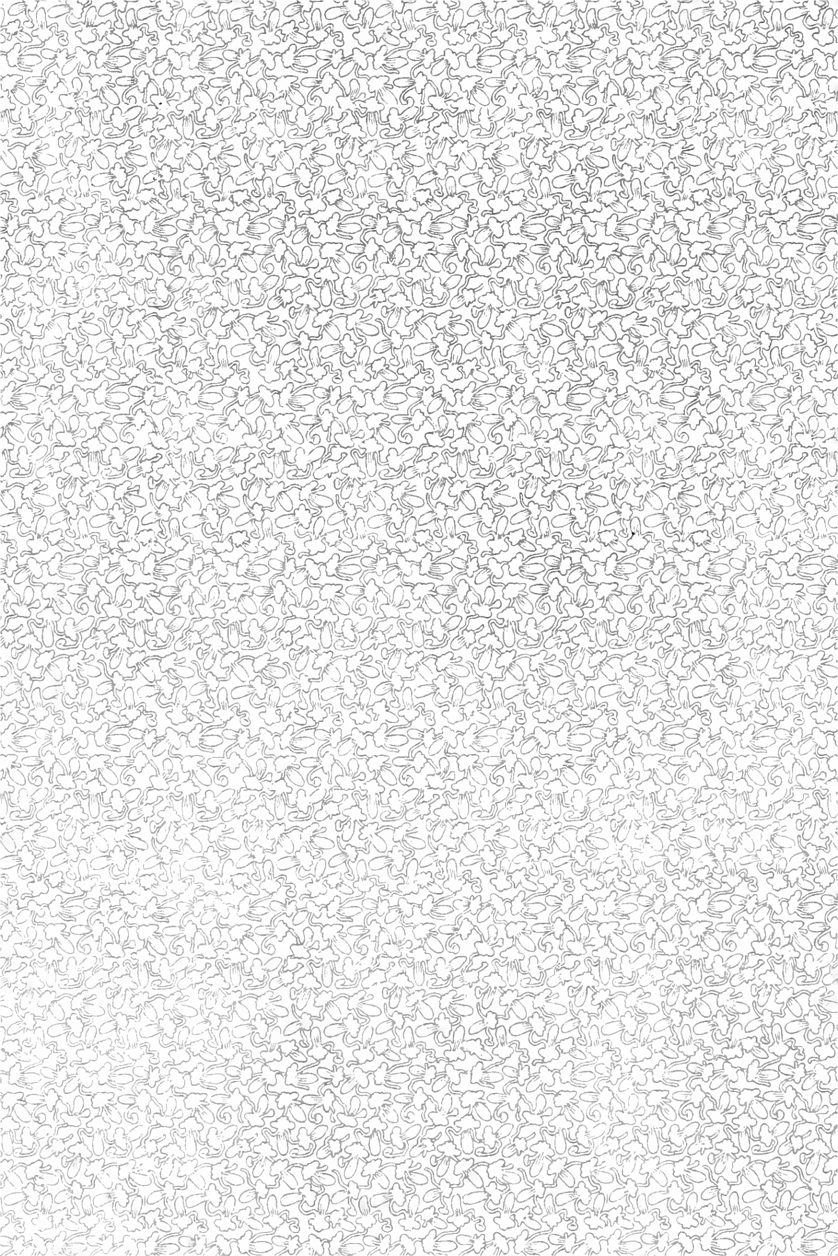
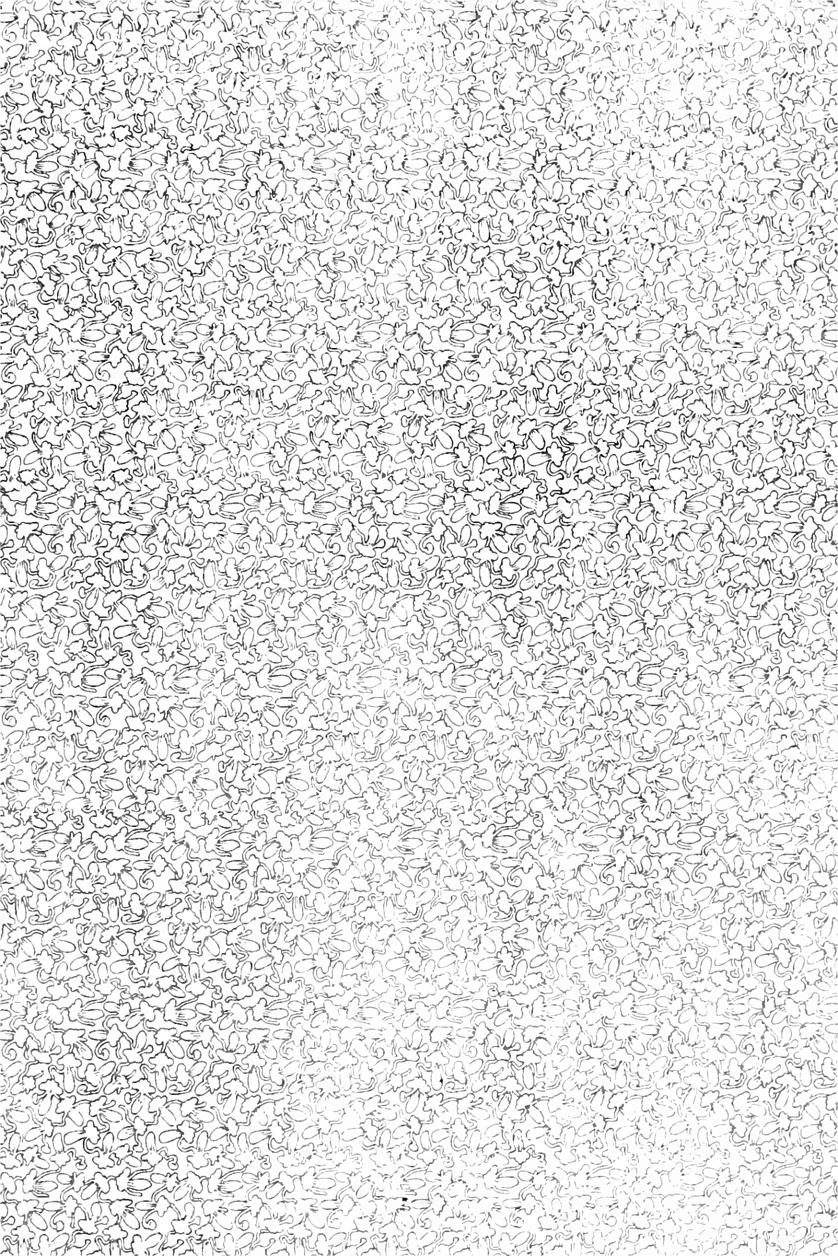
DIMMING OF LAMPS

TRACY W. SIMPSON





2903 Forest Ave.,
Berkeley, Calif.

To the President and
Faculty of the Department of
Electrical Engineering,
Armour Institute of Technology,
Chicago Ill.

Gentlemen:

I submit herewith a thesis entitled, "The Adaptation of the Multi-Tapped Auto Transformer to Dimming of Incandescent Lamps" and request that you consider this in determining my qualifications for an advanced degree.

Respectfully yours

Tracy W. Simpson

B.S. in E.E. 1909

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Advance degree

33320

THE ADAPTATION OF THE MULTI-TAPPED AUTO - TRANSFORMER TO DIMMING OF INCANDESCENT LAMPS

- BY -
Tracy W. Simpson.

The prevailing plan of dimming lamps in theatres is by the resistance method and with the demand for flexibility in control these dimming "banks" are elaborate affairs often having one hundred or more "plates" or separate control devices. The energy loss is considerable, some studies showing one fourth of the electrical energy used by an average theatre as lost in heat in the dimming bank.

With such a condition it is not surprising that a solution has been sought in the field of induction or transformer voltage regulation. The earliest dimmers were of the leakage reactance type similar to "tub" or constant current transformers. These were bulky and expensive and had an objectionable hum. Attempts have been made to vary an air gap in a two coil transformer to accomplish a similar result. The most elaborate commercial apparatus now in use is the Ward - Leonard Reactance system comprising a two coil core type transformer for each section of the load to be controlled. An auxiliary third coil is wound on the core which is connected to a variable source of direct current supply, and by causing direct current to traverse the coil the iron of the transformer becomes subjected to

a saturation as a result of the positive magneto motive

force of the direct current coil. This has the effect of moving the horizontal or zero line of the B-H curve upwards so that the variation of the primary alternating current magnetomotive force produces far less variation in the lines threading the secondary than ordinarily prevail. By altering the direct current the secondary voltage is altered and the lamps dimmed. All of these devices have the disadvantage that the power factor is seriously affected and when one realizes that a modern stage uses as much energy as many a small town the effect of such leakage reactance dimming is bound to be apparent sooner or later and the lighting companies will take cognizance of the situation.

The greatest obstacle to the existing methods of induction dimming is however it's first cost. The electrical equipment of a modern theatre at best is often as costly as the building shell and if the apparatus necessary for induction dimming on present lines be analyzed the cost will be found to be not far from twice that of resistance dimming. The theatrical business seems to be conducted on a basis of expected short time life due to changes in leaseholds, managing syndicates and the like; and the relation of operating expense to first cost and its capitalization and amortization over a long period of years is not practiced as it is in the more stable public utility business. In a word the theatre man must have low first cost even at the expense of high operating costs. If an economical device

will not save its cost in a year or so the theatre owner is generally not interested.

AN ORIGINAL INVESTIGATION OF THE PROBLEM

In casting about for a solution for this situation the writer decided to investigate the auto transformer as it is well known that this device is inherently cheap to build in th e smaller ratios of transformation such as prevail in dimming a bank of lamps; i.e. from 1 to 1 down to a 1 to x-1/4 ratio. The result is so surprisingly simple that it is hardly believable that it has not been considered before. Probably it has, theoretically, but it was doubtless at a time or under conditions when the crying need for the solution of the problem was not apparent. At least no search reveals any commercial use of the plan, and the writer believe the general scheme with the few necessary elements to the combination that make it a practical success are strictly original.

BRIEF STATEMENT OF THE PRINCIPLE

This is as follows:-

"If an auto transformer be built with a multiplicity of taps and connected through a suitable multi-point controller to a bank of Tungsten lamps said auto-transformer need not be in size, weight, or cost greater than ONE-SIXTH of a regular two coil transformer of a capacity equally capable of handling the lamps."

A further development of the principle is covered in the following:

"To insure smooth, graduated dimming with closed circuit from step to step, resistance must be inserted in each lead of such amount that the current circulating in the short circuited coil due to the contact arm bridging two contacts at once does not exceed a normal value, preferably about full load amperage.

Furthermore, instead of such resistance in the leads being deleterious a distinct benefit is obtained from the standpoint of cost as due to the resistance in the leads of the short circuited coil and the circulating current therein, a condition exists which gives the effect of an intermediate step of voltage. This may be stated as follows:-

"If the criterion of successful dimming is that the candle pwoer range be divided into a certain number of steps by any progressive method of variation, the number of contacts on the controller plate need be but one half of the said requisite number of "steps" because it is possible to adjust the resistance in the separate leads so that when the contact arm bridges two contacts it has the effect of an intermediate step in voltage."

DISCUSSION AND RATIONALIZING OF THE ABOVE CONCLUSIONS.

It will be seen that quite remarkable reductions in cost of apparatus as compared with usual methods may be obtained if the above principles be true and before proving them

theoretically let us take a practical example simple to understand and that fits into the experience of most electrical men.

We know that when 220 volts prevailed for industrial plant lighting it was customary to use a two coil transformer for feeding circuits requiring 110 volts. Gradually these 110 volt circuits grew as 220 volt lighting apparatus became more difficult to obtain. Most of us remember also how it was known that a 2 to 1 auto transformer would produce this 220-110 transformation at half the cost of a "regular" transformer, and this became quite the usual thing until the Underwriters passed their 150 volt to ground rule, causing the retirement of these auto-transformers. An auto transformer half as heavy as a 5 KW "regular" transformer or 2.5 KW frame size would care for 5 KW of secondary load at the 2 to 1 ratio. Now in dimming lamps we have the condition that as the secondary voltage goes down, the secondary load in kilowatts also decreases at an even more rapid rate. To illustrate: At half voltage a Tungsten lamp takes only 65% of full current so the power is at the rate of 32.5% of full voltage secondary power. Now inasmuch as the auto-transformer at a 2 to 1 ratio need be only half as large as a "regular" transformer it is plain that an auto transformer to operate say 50 one hundred watt lamps at half voltage need be of the same frame size as a "regular" transformer of 16.25% of 5 KW. That is to say, any 800 watt two-coil transformer [illegible] around

as an auto-transformer should operate 5 K of lamps at half voltage with no more heating than it had when a two coil 800 watt transformer.

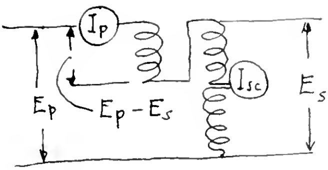
Reference to the Tungsten lamp characteristic curves for other voltages shows similar results; i.e. that the "equivalent transformer" rating of the device will vary from zero at full voltage (no dimming) up to a maximum of about 17.5% of the lamp load rating at 20% of candle power and then drop off to 11 percent at the 1 to 1/4 ratio that barely causes the lamps to glow.

GENERAL THEORY

The curves on drawing No. 673 show these relations. As the principle reference or variable is the "Candle Power of Lamps" it is best to refer all factors as candle power is altered to their value as a percent of their value at full candle power.

The curves R_s, I_s, and "volts at lamps", representing resistance, current and voltage at lamps with variable candle power are taken from the Mazda Lamp Engineering Data Book and provide the starting point. E_s or "volts in transformer" is slightly higher due to resistance in leads. Secondary watts $E_s I_s$ is directly plotted and as the primary voltage is constant this curve will also represent percentage variation of primary current, neglecting slight internal losses. The watts transformed which represents the

electro magnetic work done in the device and is a measure of its weight and cost can now be obtained by first determining the current in the secondary part of the coil from the following relation:



$$(E_p - E_s) I_p = E_s I_{sc}$$

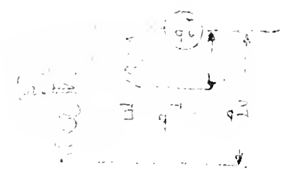
or

$$I_{sc} = \left(\frac{E_p}{E_s} - 1\right) I_p$$

This value I_{sc} is shown on the chart and by multiplying by E_s the true electro-magnetic transformation in the device is obtained. This is plotted on a double sized scale of abscissa to show its detail.
A study of the internal currents at the various ratios of transformation show also that considerable economy of copper may be had by dividing the coil into three sections in large auto-transformers and in two sections in smaller ones.

The proof of the principle that the addition of resistance leads amounts to the same thing as an intermediate point of dimming is easily shown by applying Kirchoff's laws to the branch circuit. Assume in the diagram below for example the conditions at point 18 and 19 of the transformer whose design is shown in the drawing.

When the brush is on point 18 the actual volts will be the



generated volts less the drop in resistance lead or 79 - 24X.07 or 77.3 volts. When on point 19 it will be 76 - 23X..08 or 74.1 volts.

When the two points are short circuited, if we let X equal amperes through ACB (See diagram) and Y equal amperes through AB, then

$x + y = 23.5$ let us say

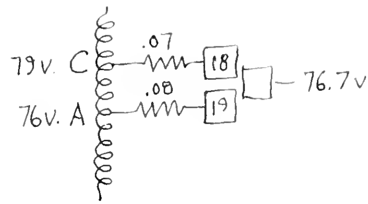
(See chart for value of I_s

$-3 + .07x = .08y$

equalizing volt drop

whence $y = -9.1$ amps

$x = 32.6$ amps



and the volts at terminal is 76.7

This is not half way between but it is enough of a jump to materially improve the action of the device. The relative position that this figure has to the volts at adjacent points cannot be altered much by wide variations of resistance in the leads provided their relative value is the same.

COMPARISON OF ECONOMY OF OPERATION WITH THAT OF RESISTANCE DIMMING.

The saving in power due to the use of this device for the purpose of dimming as compared with the usual method of dimming with rexistance plates is easily read directly from the characteristic curve. Thus the curve of secondary amp. variation I_s is also the curve of variation of total current

input at the various candle powers if resistance dimming be used. The curve of power input when induction device is used is that shown on the chart as "Secondary Watts." Therefore the saving of this device as compared with resistance dimming is measured by the horizontal distance between the curves of I_s and E_s I_s and may be directly read from the curve sheet as a percent of the full candle power wattage of the bank of lamps, as for instance:

WATTS LOST IN DIMMING BY THE RESISTANCE METHOD AS A PERCENTAGE OF TOTAL WATTAGE OF THE LAMPS AT FULL CANDLE POWER.

This amount is saved in device under discussion.

Candle Power of Lamps	Percent of full candle power wattage of lamp bank.
100%	0 %
80	5
60	11
40	17.5
20	28
10	33
0 (barely glow)	35

The above factors give the quickest way of determining the watts saved by the device under discussion for any condition of candle power of the lamps. It does not however show the true percentage of amount saved of the proposed device as compared with resistance dimming. The latter percentage is of course, for any given candle power

$$\frac{\text{Watts used by resistance method} - \text{watts used by induction method}}{\text{Watts used by resistance method}} \times 100$$

which is given in table below:

PERCENTAGE OF SAVING OF DEVICE UNDER DISCUSSION AS COMPARED WITH RESISTANCE METHOD

Candle Power of Lamps	Percent power saved
100%	0
80%	5.4%
60	12.0
40	20.4
20	36.2
10	49.0
0 (barely glow)	70.0

Now in the actual operation of a dimming bank in a theatre the time that the handles are set to produce 60 to 80 per cent of candle power is very small indeed, being only in the transition down to the usual "Dim" of a darkened stage and the majority of the time that the dimming handles are in use at all will find them somewhere in the lower ranges of candle power. The saving at these ranges is seen from the table to be quite marked.

All of the above refer to power savings and do not show energy saving for a cycle of the show. The latter is more difficult to estimate, and in fact cannot be done, of course, unless the time-dim requirements for the show are known. There is one phase of it however that bears invest-

igation at this point and that is to determine under what condition it is best to go to the complication on the control device of having an auxiliary arm that will cut out the auto-transformer from the circuit when full voltage is desired thus eliminating the open circuit core losses of the device.

For instance, if the device is accross the line during all the time that the bank of lamps is on, even though steady burning at full voltage, the energy loss in the device will be the kilowatt hours lost in the core for the time it was connected. This energy of course must be subtracted from the energy saved by the device during the time bank is dimmed.

In the design of auto-transformer shown on the drawing, which is typical of what may be expected of devices of this character the core loss at 60 cycles is at the rate of 14 watts, or 14 watt hrs. per hr. At 20% candle power 14 watt hrs. is saved as compared with resistance dimming in 55 seconds. We therefore conclude that the point at which the saving equals the losses in the device will be reached if the dimmer is in use to produce 20% full candle power 55/3600 of the time; i.e. 1.5% of the time., The conclusion as to whether the expense of an extra arm on the control device is justified will therefore depend upon the character of the time-dim curve, and the reasoning for determining

the answer in any particular case is suggested sufficiently in the above. For the usual photoplay house or theatre the economics of the proposition will show that such an additional arm to eliminate core losses when the lamp bank is burning full voltage is justified as it will save its cost in about a year, but that for lodges, schools and places where the productions are intermittent it is a needless and uneconomic addition. We therefore conclude that in the manufacture of a line of dimming equipment embodying the device under discussion an auxiliary arm to cut out the auto-transformer when lamps are at full voltage will be included on all "theatre type" units but we will eliminate the same from all "lodge type" units - to use the parlance of the resistance dimmer catalogs.

COMPARISON OF FIRST COST OF DIMMING SYSTEM USING THE DEVICE UNDER DISCUSSION WITH COST OF RESISTANCE DIMMING.

In considering this matter we are under the handicap of having to discuss the expected cost of manufacture of the device proposed with the selling price to switchboard manufacturers of resistance dimming equipment. The correct method is of course to compare the cost to make the new device with the cost to make the old. If the same sub division of control plates and flexibility is insisted upon with the new system as with the old (and we will show later that this is not at all an essential premise) the best way to show relative costs is to take a typical specification

for a theatre and compare the two. For purpose of discussion let us take the case of the Indiana Theatre at Terra Haute, Indiana which has a complete schedule of dimming apparatus referred to in Crofts "Lighting Circuits and Switches" First Ed. pp 436-437.

The cost of operating handles and interlocking shafts for the two systems may be said to be the same with the advantage if any in favor of the induction system. This is for the reason that the largest standard resistance theatre plate is 30 amps, and for dimming say the white circuit in the footlight 9000 watt three wire, the resistance system will require four plates and the induction system only two plates. The cost of tying these plates mechanically together is therefore less in the induction system, also less support and room on the board is required.

The cost to a switchboard manufacturer of the plates only for the resistance dimming system of the Indiana Theatre was probably about $2060 the same comprising 59 plates.

In the induction system we would tie the proscenium strips to the foots as when one is dimmed the other is dimmed, and have a disconnect between them on the low voltage side and the job be taken care of with the following equipment:

		amp	2	wire	control	plates	each	with	one			
2	60	"	"	"	"	"	"	"	Two	6.6	KVA	Coil
12	30	"	"	"	"	"	"	"	"	3.3	"	"
3	30	"	3	"	"	"	"	".	two	3.3	"	"
7	60	"	"	"	"	"	"	"	"	6.6		

The number of controller plates is reduced from 59 to 34 as compared with resistance system.

As to the cost of these devices a survey with a small transformer manufacturer and a switchboard manufacturer seems to indicate that auto-transformer coils with 50 taps, providing 100 steps of dimming may be had for prices as follows when on a manufacturing basis of at least a hundred at a time:

3.3 KVA Coils complete in case $14.50 each
6.6 " " " " " $19.50 each
11.0 " " " " " $25.50 each

The cost of 50 point control plates similar to illustration but with auxiliary cut out arm, providing 100 steps of dimming is estimated on the same production basis to be as follows:

30 amp plates $20.00 each
60 amp plates $30.00 each. 3 wire controllers double price
100 amp plates $50.00 each.

The above prices are selling prices to an assembler therefore they may be presumed to contain a factory overhead and small profit.

Applying the above estimates to the Indiana Theatre job we have for apparatus equivalent to that furnished by the resistance dimmer manufacturer for $2060.00. a cost of $1413.00, or a saving of $547.00 in first cost on the Indiana Theatre job.

It must be recognized that in the above we are comparing the costs to a switchboard manufacturer. The chances are that the resistance dimmer manufacturers have figured in their prices considerably more overhead and profit than the small manufacturer who would make auto-transformers and control plates on sub-contract so that if absolute costs, labor, and material were compared the advantage shown by induction apparatus might be wiped out.

Even so the comparison is quite favorable indeed as it is apparent from the savings to be expected in operation the induction apparatus should command a much higher price in the market.

It will be recalled that the preceding comparison is based upon equal flexibility. As a matter of fact, however, the flexibility of stage lighting is in some respects merely an after effect of the great sub-division in switching necessary due to the fact that dimmer plates cannot be made larger than 30 amps. under ordinary space limitations (The Ward Leonard Company has just announced its largest continuous dimmer plate is reduced to 27 amps.) and also that in the resistance system each plate must have a rating exactly corresponding to the rating of the load to which it is connected. In the induction system proposed no such limitation exists as a 100 amp. control plate and 11 KVA coil will dim one 50 watt lamp as efficiently and with the same gradation of con-

trol as it will care for 11,000 watts. It will thus be seen that considerable simplification and consolidation may be permitted and at great savings of cost by using centralized induction units and disconnecting switches on the low voltage side. For instance in the Indiana Theatre job previously considered, there is no good reason why all the amber house lights should not be on one three wire control plate and disconnecting switches placed on the low voltage side to eliminate one or all of balustrades, and oriole grills. It is inconceivable that there would be any practical reason for wanting to dim the balustrade ambers "up" while dimming the oriole grill ambers "down", or to dim either at a different rate than the amber side coves. What is wanted is to be able to dim, any combination of the three up or down and to eliminate one or two from the three at will. This is easy to do by the proposed device.

Whereas the Indiana Theatre schedule shows only a front and back border which probably should be separated so one can be dimmed "up" while one is dimmed "down" such a condition would be simplified in a larger stage with 4 to 6 borders, For instance Border No. one could have one control equipment. Border No. 2 and No. 3 could be consolidated on one control plate with disconnecting switches on the low voltage side. Similarly Border No. 4 and 5 could be consolidated on one control plate. Such a plan would provide all the flexibility that one has reason to expect.

In the case of the pockets and cradle spot dimmers a most important condition must be examined. The dimmer on the board is arranged to carry the maximum load that it is expected the pockets will ever have connected to them at one time. If it is desired to obtain accurate dimming from a pocket in only one or two places such as for a couple of 500 watt spots it is customary practice to do what is called "load up the pockets" by inserting a battery of large Olivette lights in the other pockets and turning their face to the wall thus causing an outright waste of the electricity they use. All this would be avoided by the induction apparatus. The chances are that the most fertile field for the sale of the new device would be found in replacement of existing resistance dimmers on the pocket and cradle spot panels of existing switchboards. This would be so obvious that the trade should take to it readily and it would be a good preliminary to campaigning for general replacement of the entire board.

CONSOLIDATION OF SYSTEM OF CONTROLLER PLATES TO ONE OR MORE AUTO-TRANSFORMERS.

It is to be observed that there is nothing to prevent more than one controller plat being connected to a single auto transformer. For instance in a theatre there may be only four such auto transformers, two for the stage lighting and two for the house lighting, each one connected to opposite sides of a three wire system. If these are of suffi-

cient size they will handle all the controller plates. There is, however, an objection to this plan in that if one transformer should burn-out whole sections of the theatre would be inoperative; further one as the various sections of the coils in the auto-transformer were short circuited by the various controller plate arms bridging adjacent contacts there would be a variation of voltage on everything connected to that auto-transformer. To take an extreme case of a 50 point transformer feeding 50 controller plates, each controller might be bridging a different coil from any of the others. In such case the current in the winding would be so great that the supply would be so heavily drawn upon to maintain any semblance of voltage that primary fuses would certainly blow.

DISCUSSION OF NUMBER POINTS OR STEPS OF DIMMING.

Resistance dimmers have an arrangement of steps the number of which is dictated by two considerations; the number of candle power steps necessary to prevent jumping, and the limitations of the area of a radiating disk housing the resistance coil. For some time the writer has suspected that there is no real reason for having as many steps of dimming as provided by the commercial resistance dimmers from the standpoint of candle power jumps. Tests made on resistance dimmer plates show the arrangement to be based upon substantially equal variations of candle power from step to step.

It would appear in theory that the number could be reduced by having each step bear a definite ratio to the candle power of the step adjacent: that is, use geometric progression instead of arithmetic. This would seem to be expected by a consideration of the physiology of the sensation of jumping of lighting. It would appear to be true that within the ranges of normal illumination with no glare or eye strain if the eye could detect a variation of 5% in illumination from a normal and could not detect a 4% variation from a normal, then regardless of the absolute illumination the same ratio would prevail. Experiment seems to indicate there is some truth in this and it is well known that the jumping sensation in dimming of existing resistance type dimmers is more apparent at low dimming than near the top. This would be caused by the arithmetic progression of candle power, thus if the steps are arranged in 100 equal parts of candle power the progression from step 3 to 4 is an increase of 33% of what it was at point 3 causing a distinct sensation of jump, whereas from 98 to 99 the variation is 1% or drawn too fine.

The transformer design submitted in connection herewith has arithmetic progression by equal steps from 100% to 20% candle power, thence by steps of half as great to zero candle power. Additional devices built show an improvement if the steps are divided geometrically down to about 10% of candle power thence arithmetically for the balance to avoid the

number of steps becoming infinite.

It is also found that the number of steps necessary for white dimming is not the same as needed for colors. Blue dimming can take place with half the steps of white dimming due to the tremendous absorbtion of blue color screens. Red is so colorful that it seems to need the same number of steps as white, but a great saving can be made in controller manufacturing cost if the steps for the blues are reduced one half.

CLAIMS TO ORIGINALITY

In the preceding discussion it is evident that claims for apparatus as well as a complete combination or system can be made embodying the entire use of the device for dimming lamps or regulating voltage on other devices that have similar approximately constant resistances. The auto-transformer is old, but its use in such a combination involving resistance in the leads, the auxiliary cut out arm, and on a large bank is new. Analyzing the situation the writer would claim to be new as follows:-

(1) In an auto transformer or transformer a multiplicity of taps each giving different terminal voltages with resistance inserted in each lead of such value as to substantially limit the current in the part of coil of transformer or auto-trans-

former between any two such adjacent taps to such amount as will not cause undue heating or humming in said coil.

(3) In an auto transformer or transformer a multiplicity of taps each giving different terminal voltages with resistance inserted in each lead of such value that errors in winding transformer to produce a predetermined terminal voltage may be corrected by alteration of resistance in said tap.

(4) In an auto-transformer or transformer a multiplicity of taps each giving different terminal voltage with resistance inserted in each lead of such value that when any two such adjacent taps are connected to one or more switch contacts or arms the voltage at any such contact will be intermediate between the voltage at each adjacent tap when said contact is not connected to said adjacent taps.

(5) An autotransformer or transformer having a multiplicity of taps each one with or without resistance in leads, one or more controller plate to connect leads therewith to each tap successively each said load to be substantially non-inductive and having its internal resistance from the nature thereof vary within a range of from 55% of its maximum value when connected with any said tap to said maximum value, as said loads are connected successively to said taps.

(6) An auto transformer or transformer having a multiplicity of taps each one with or without resistance in leads the

arrangement and connection of said taps being such that the terminal voltage will progress successively from each tap to the one adjacent thereto so that the candle power of a lamp bank connected to such device will vary in substantially equal steps of candle power from maximum to minimum or vice versa as connection is made successively from tap to tap singly and individually even though the intermediate step of candle power when the connecting device is on two adjacent points of the controller is unequal.

(7) An auto-transformer or transformer having a multiplicity of taps each one with or without resistance in leads the arrangement and connection of said taps being such that the terminal voltage will progress successively from each tap to the one adjacent thereto so that the candle power of a lamp bank connected to such device will vary in substantially steps of geometric progression of candle power from maximum to minimum or vice versa as connection is made successively from tap to tap singly and individually even though the intermediate step of candle power when the connecting device is on two adjacent points of the controller may not so vary.

(8) An auto transformer or transformer having a multiplicity of taps each one with or without resistance in leads, one or more controller plates to connect loads, therewith to each tap successively, a switch interlocked with the operating mechanism of said controller plates so arranged that said auto-transformer or transformer may be connected to or disconnected from supply circuit without any disconnection of the connected loads from the supply circuit.

APPENDIX A

[illegible]

In [illegible] of low [illegible] actual [illegible] ing th[illegible] principle [illegible] lating [illegible] for [illegible] proportioning of [illegible] leads so that the watts dissipated therein, particularly [illegible] tain steps, would avoid operating at a temperature [illegible] safe for the resistance material.

The curve sheet attached shows details of the arrange-ment of steps in a commercial line of [illegible], and the [illegible] for maximum watts dissipated in leads is developed [illegible] in the lower right corner thereof. The table shows the determining factors for the design of the resistance; viz, [illegible] and watts dissipated. Any alloy used for the coils has characteristics obtainable from the manufacturer as to watts that may be radiated per foot for the various sizes of wire.

It is a two to one chance that the operator will keep the controller arm bridging two adjacent points so that loss in leads due to circulating current is the main factor in calculating the efficiency of the device. At less than 4% candle power it is the worst with a loss of 3.2% of full voltage lamp bank rating or 15% of the power used by the lamps at 5% of full candle power. At half candle power it is 9/10 of 1% of full voltage lamp bank rating or 1.25% of power used by lamps at that candle power.

The curve also shows the arrangement of steps in [illegible] progression with arithmetic progression in the [illegible].

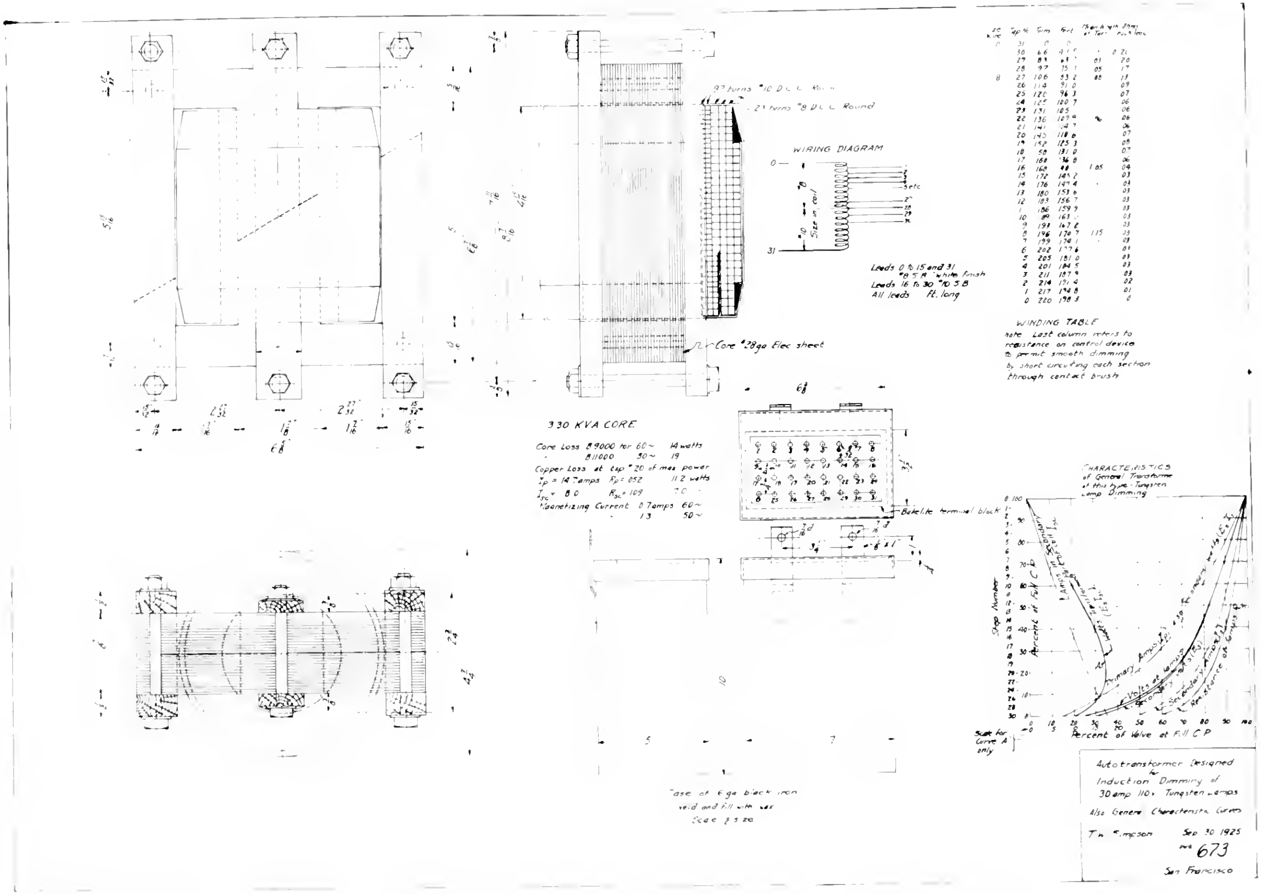
APPENDIX B

USE OF INDUCTIVE REACTANCE IN PLACE OF RESISTANCE.

The control of the short circuit current [illegible] by causing each [illegible] inside or outside of the transf[illegible] the control mechanism. [illegible] for the 30 [illegible] for the [illegible] Cal-culat[illegible] a con[illegible] can [illegible] inside [illegible] when [illegible]

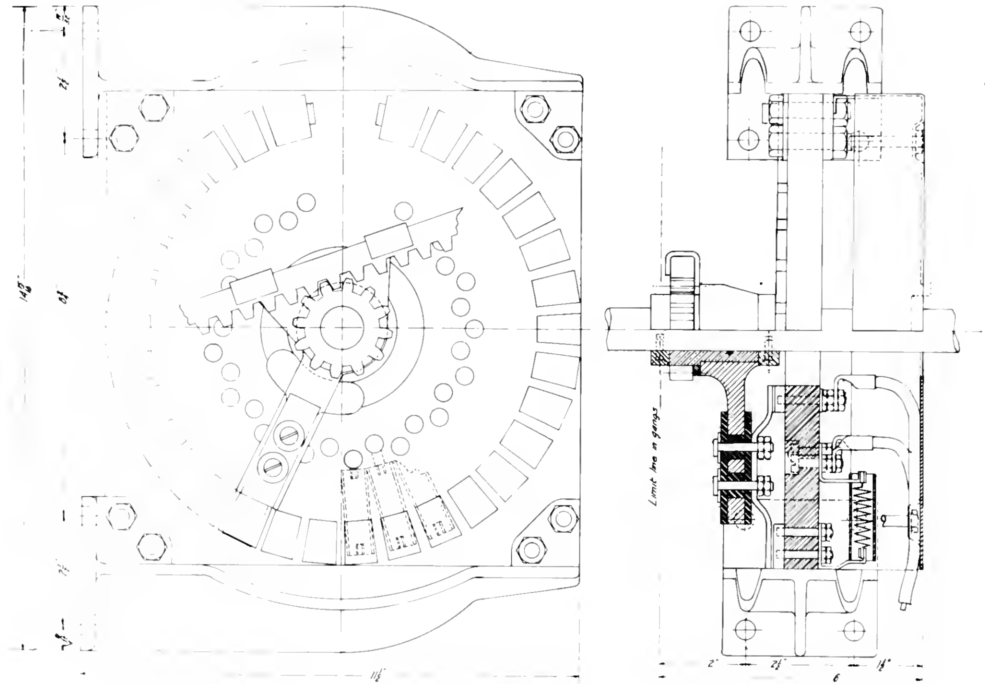
[illegible] single [illegible] the [illegible] "[illegible] construc[illegible] tr[illegible] [illegible] shoul[illegible]

[illegible] which [illegible] circuit current [illegible] be [illegible].

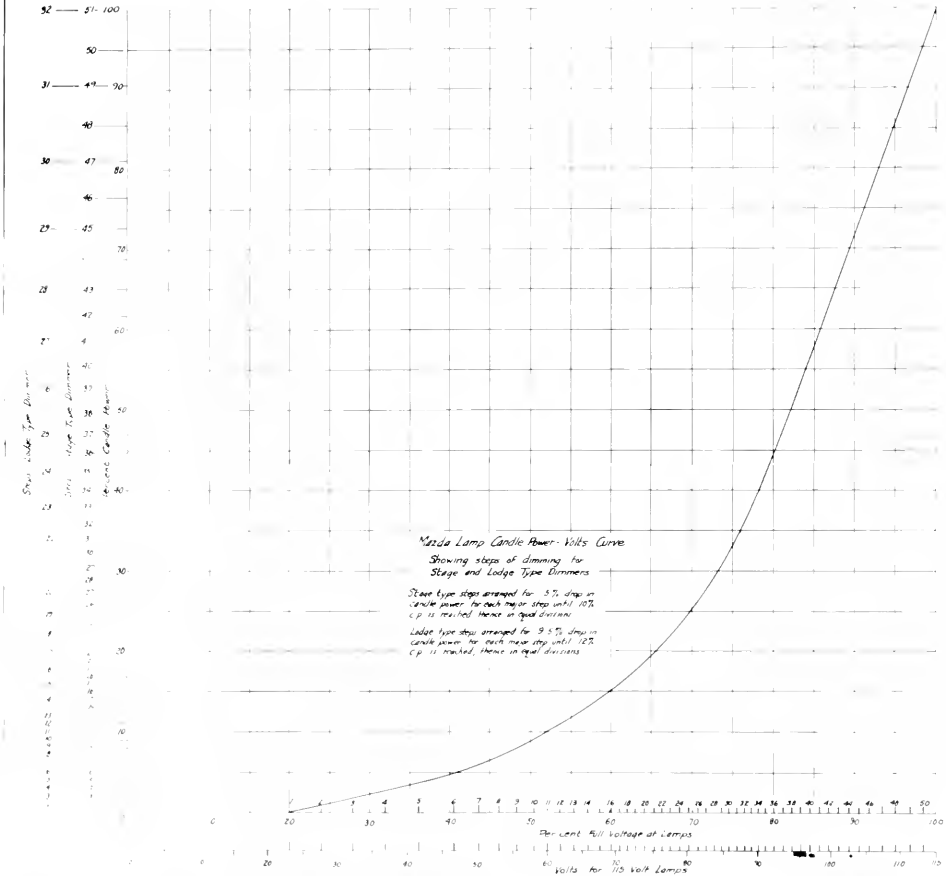


Size Wire	Tap No	Turns	Feet	[illegible] at Tap	[illegible]
0	31	0	0		
	30	66	[illegible]		0.21
	29	83	[illegible]	.01	.20
	28	97	75.1	.05	.17
8	27	106	83.2	.08	.13
	26	114	91.0		.09
	25	120	96.3		.07
	24	125	100.7		.06
	23	131	105		.06
	22	136	109.9		.06
	21	141	[illegible]		.06
	20	145	118.6		.07
	19	152	125.3		.08
	18	[illegible]	131.0		.07
	17	160	136.8		.06
	16	168	[illegible]	1.05	.04
	15	172	145.2		.03
	14	176	147.4		.03
	13	180	153.6		.03
	12	183	156.7		.03
	11	186	159.9		.03
	10	[illegible]	163		.03
	9	193	167.2		.03
	8	196	170.7	1.15	.03
	7	199	174.1		.03
	6	202	177.6		.03
	5	205	181.0		.03
	4	201	184.5		.03
	3	211	187.9		.03
	2	214	191.4		.02
	1	217	194.8		.01
	0	220	198.3		0

WINDING TABLE
note Last column refers to resistance on control device to permit smooth dimming by short circuiting each section through contact brush



Control for Induction
Dimmer
Capacity 3000 watts
of Tungsten lamps
T W Simpson Sep 30 1925
No 672
San Francisco



Mazda Lamp Candle Power - Volts Curve

Showing steps of dimming for Stage and Lodge Type Dimmers

Stage type steps arranged for 5% drop in candle power for each major step until 10% c p is reached thence in equal divisions

Lodge type steps arranged for 9.5% drop in candle power for each major step until 12% c p is reached, thence in equal divisions

Proportions and Design Factors (Heat to be dissipated in Resistance in leads to prevent overheating of short circuited coil

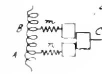
For Stage Dimmers - 51 points 102 steps

30 Amp Size		60 Amp Size		100 Amp Size		
Ohms in each lead	Max watts to be dissipated	Ohms in each lead	Max watts to be dissipated	Ohms in each lead	Max watts to be dissipated	
0.08	112	0.04	224	0.024	336	Leads 1 to 5
0.06	63	0.03	126	0.018	210	6 to 10
0.04	41	0.02	82	0.012	136	11 to 16
0.03	32	0.015	64	0.009	107	17 to 24
0.02	30	0.01	60	0.006	100	25 to 51

For Lodge Type Dimmers - 32 points 63 steps

0.08	112	0.04	224	Not made in 100 amp size
0.06	105	0.03	210	

Formula for watts to be dissipated in lead resistance



Let

x = amps in BC

y = " AC

m = ohms BC

n = " AC

a = volts generated in AB

b = amps at C (Obtain from resistance of lamp bank)

Then

$x + y = b$

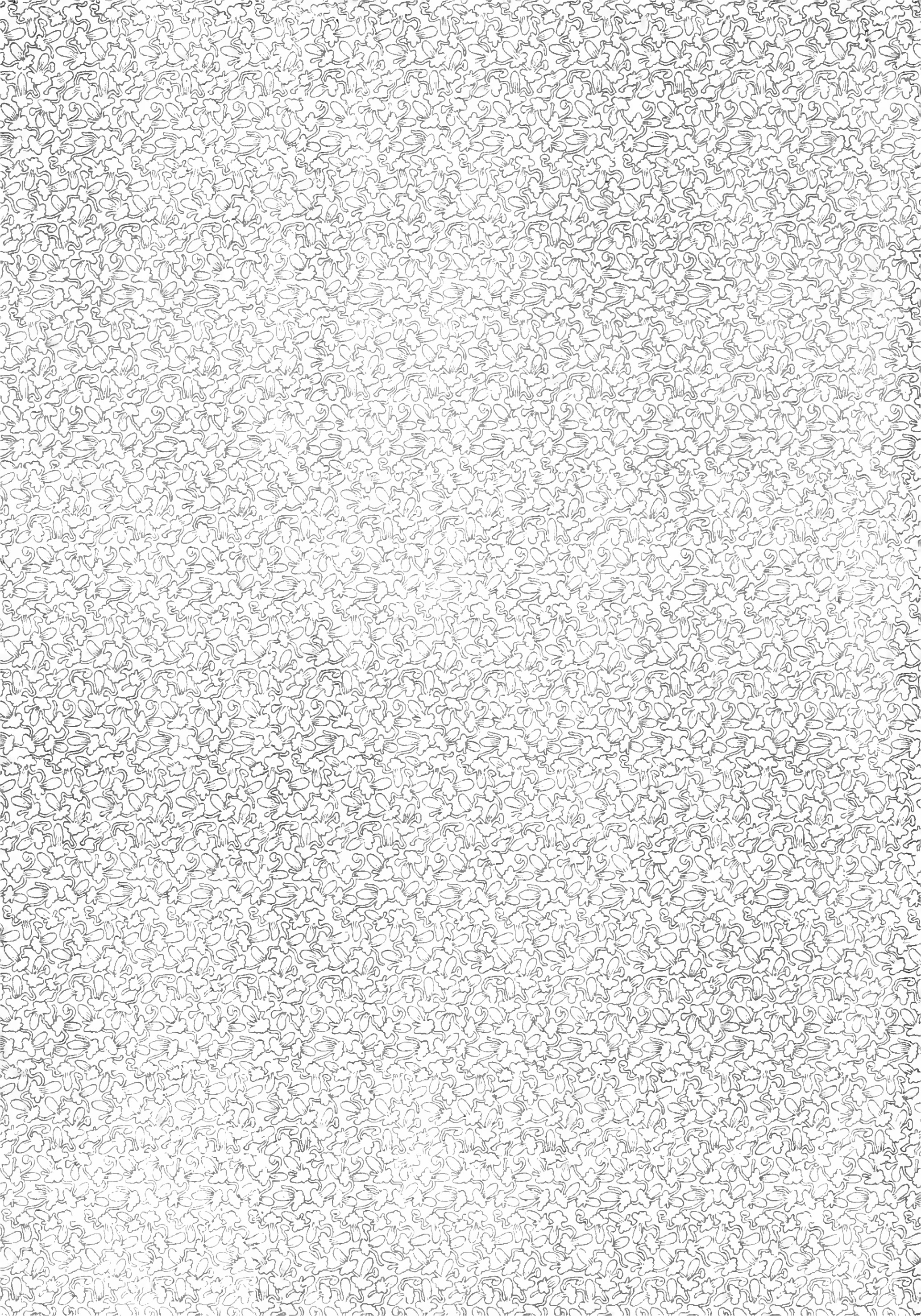
$-a + xm = yn$

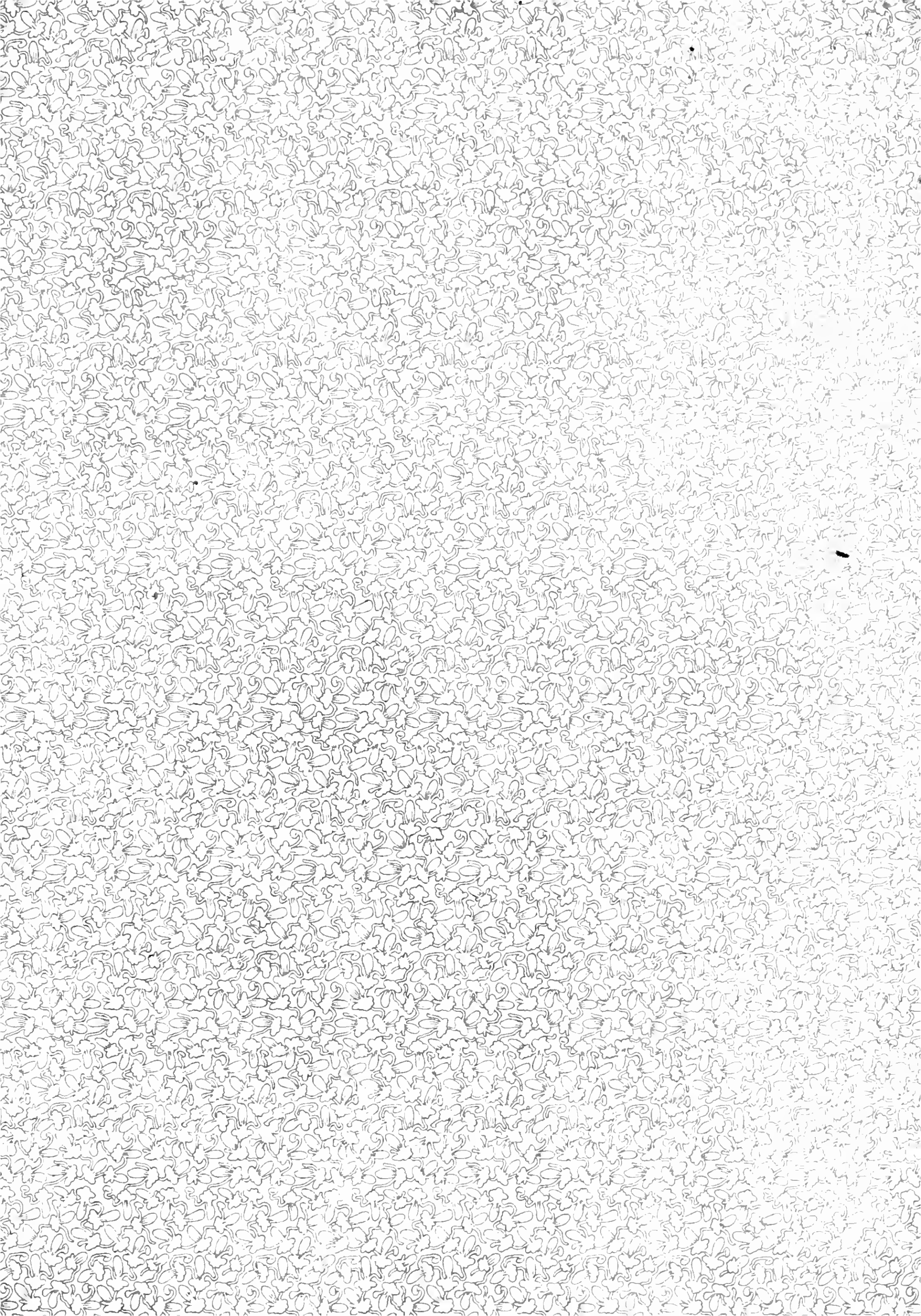
From which $y = -\frac{a-bm}{n+m}$ $x = b + \frac{a-bm}{n+m}$

x being the larger

Max watts dissipated $= m\left(b + \frac{a-bm}{n+m}\right)^2$

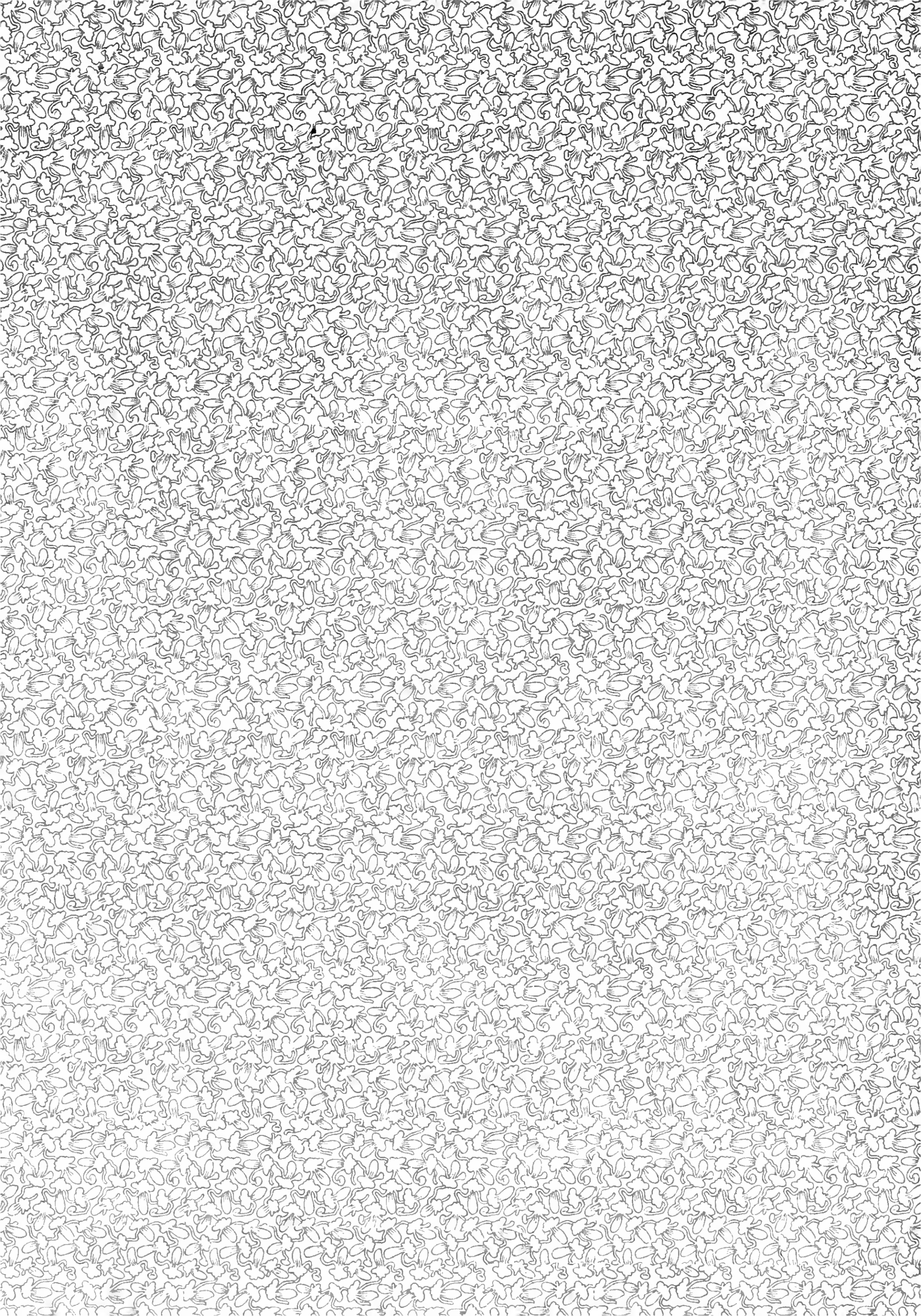
T. R. Simpson Oct 5

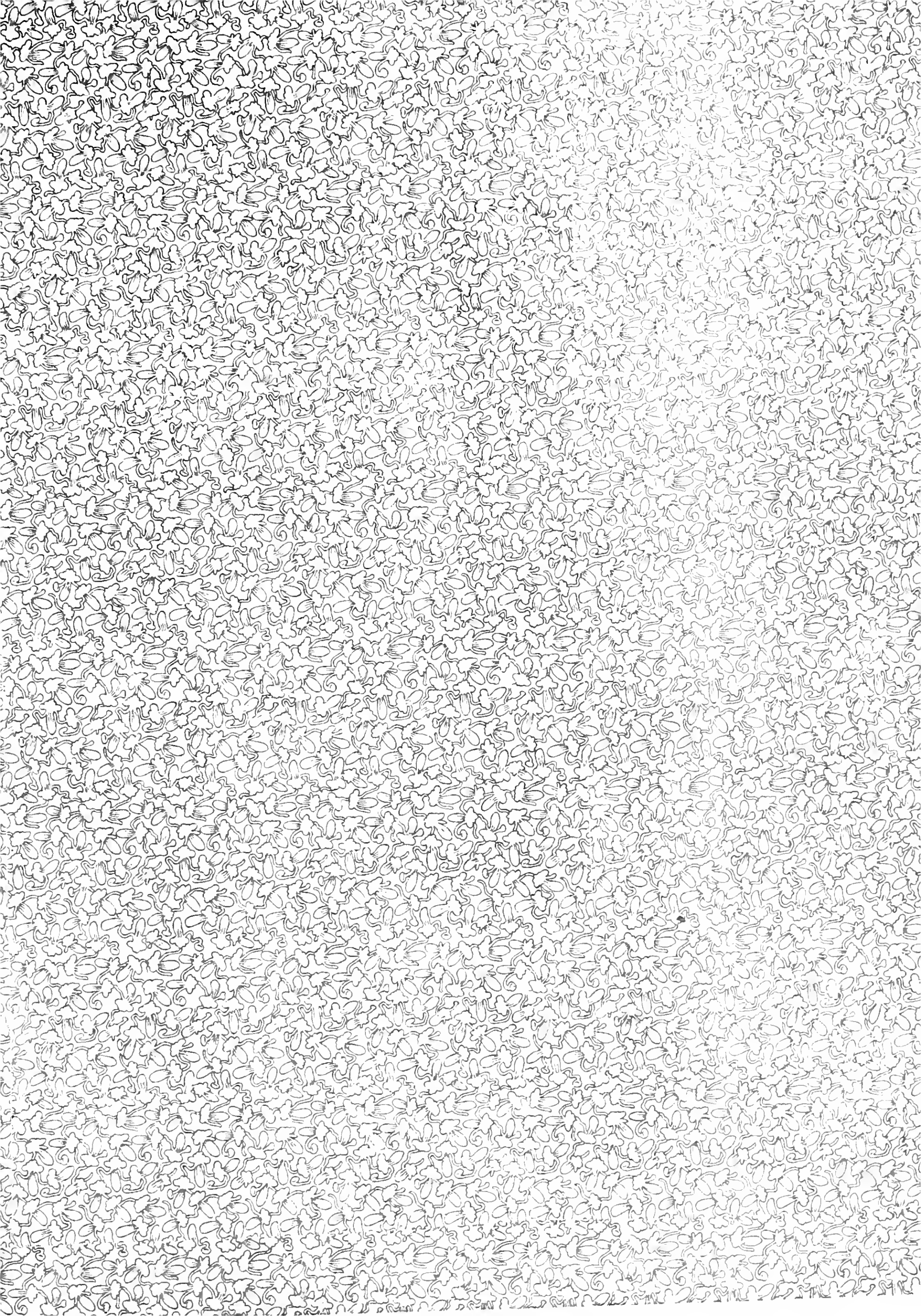




DIMMING OF LAMPS

TRACY W. SIMPSON





2903 Forest Ave.,

Berkeley, Calif.

To the President and
Faculty of the Department of
Electrical Engineering,
Armour Institute of Technology,
Chicago Ill.

Gentlemen:

I submit herewith a thesis entitled, "The Adaptation of the Multi-Tapped Auto Transformer to Dimming of Incandescent Lamps" and request that you consider this in determining my qualifications for an advanced degree.

Respectfully yours

Tracy W. Simpson

B.S. in E.E. 1909

Jan. 15th. 1926

approved
E. H. Freeman

THE ADAPTATION OF THE MULTI-TAPPED AUTO - TRANSFORMER TO DIMMING OF INCANDESCENT LAMPS

- BY -
Tracy W. Simpson.

The prevailing plan of dimming lamps in theatres is by the resistance method and with the demand for flexibility in control these dimming "banks" are elaborate affairs often having one hundred or more "plates" or separate control devices. The energy loss is considerable, some studies showing one fourth of the electrical energy used by an average theatre as lost in heat in the dimming bank.

With such a condition it is not surprising that a solution has been sought in the field of induction or transformer voltage regulation. The earliest dimmers were of the leakage reactance type similar to "tub" or constant current transformers. These were bulky and expensive and had an objectionable hum. Attempts have been made to vary an air gap in a two coil transformer to accomplish a similar result. The most elaborate commercial apparatus now in use is the Ward - Leonard Reactance system comprising a two coil core type transformer for each section of the load to be controlled. An auxiliary third coil is wound on the core which is connected to a variable source of direct current supply, and by causing direct current to traverse the coil the iron of the transformer becomes subjected to a saturation as a result of the positive magneto motive

force of the direct current coil. This has the effect of moving the horizontal or zero line of the B-H curve upwards so that the variation of the primary alternating current magnetomotive force produces far less variation in the lines threading the secondary than ordinarily prevail. By altering the direct current the secondary voltage is altered and the lamps dimmed. All of these devices have the disadvantage that the power factor is seriously affected and when one realizes that a modern stage uses as much energy as many a small town the effect of such leakage reactance dimming is bound to be apparent sooner or later and the lighting companies will take cognizance of the situation.

The greatest obstacle to the existing methods of induction dimming is however its first cost. The electrical equipment of a modern theatre at best is often as costly as the building shell and if the apparatus necessary for induction dimming on present lines be analyzed the cost will be found to be not far from twice that of resistance dimming. The theatrical business seems to be conducted on a basis of expected short time life due to changes in leaseholds, managing syndicates and the like; and the relation of operating expense to first cost and its capitalization and amortization over a long period of years is not practiced as it is in the more stable public utility business. In a word the theatre man must have low first cost even at the expense of high operating costs. If an economical device

will not save its cost in a year or so the theatre owner is generally not interested.

AN ORIGINAL INVESTIGATION OF THE PROBLEM

In casting about for a solution for this situation the writer decided to investigate the auto transformer as it is well known that this device is inherently cheap to build in th e smaller ratios of transformation such as prevail in dimming a bank of lamps; i.e. from 1 to 1 down to a 1 to x-1/4 ratio. The result is so surprisingly simple that it is hardly believable that it has not been considered before. Probably it has, theoretically, but it was doubtless at a time or under conditions when the crying need for the solution of the problem was not apparent. At least no search reveals any commercial use of the plan, and the writer believe the general scheme with the few necessary elements to the combination that make it a practical success are strictly original.

BRIEF STATEMENT OF THE PRINCIPLE

This is as follows:-

"If an auto transformer be built with a multiplicity of taps and connected through a suitable multi-point controller to a bank of Tungsten lamps said auto-transformer need not be in size, weight, or cost greater than ONE-SIXTH of a regular two coil transformer of a capacity equally capable of handling the lamps."

A further development of the principle is covered in the following:

"To insure smooth, graduated dimming with closed circuit from step to step, resistance must be inserted in each lead of such amount that the current circulating in the short circuited coil due to the contact arm bridging two contacts at once does not exceed a normal value, preferably about full load amperage."

Furthermore, instead of such resistance in the leads being deleterious a distinct benefit is obtained from the standpoint of cost as due to the resistance in the leads of the short circuited coil and the circulating current therein, a condition exists which gives the effect of an intermediate step of voltage. This may be stated as follows:-

"If the criterion of successful dimming is that the candle pwoer range be divided into a certain number of steps by any progressive method of variation, the number of contacts on the controller plate need be but one half of the said requisite number of "steps" because it is possible to adjust the resistance in the separate leads so that when the contact arm bridges two contacts it has the effect of an intermediate step in voltage."

DISCUSSION AND RATIONALIZING OF THE ABOVE CONCLUSIONS.

It will be seen that quite remarkable reductions in cost of apparatus as compared with usual methods may be obtained if the above principles be true and before proving them

theoretically let us take a practical example simple to understand and that fits into the experience of most electrical men.

We know that when 220 volts prevailed for industrial plant lighting it was customary to use a two coil transformer for feeding circuits requiring 110 volts. Gradually these 110 volt circuits grew as 220 volt lighting apparatus became more difficult to obtain. Most of us remember also how it was known that a 2 to 1 auto transformer would produce this 220-110 transformation at half the cost of a "regular" transformer, and this became quite the usual thing until the Underwriters passed their 150 volt to ground rule, causing the retirement of these auto-transformers. An auto transformer half as heavy as a 5 KW "regular" transformer or 2.5 KW frame size would care for 5 KW of secondary load at the 2 to 1 ratio. Now in dimming lamps we have the condition that as the secondary voltage goes down, the secondary load in kilowatts also decreases at an even more rapid rate. To illustrate: At half voltage a Tungsten lamp takes only 65% of full current so the power is at the rate of 32.5% of full voltage secondary power. Now inasmuch as the auto-transformer at a 2 to 1 ratio need be only half as large as a "regular" transformer it is plain that an auto transformer to operate say 50 one hundred watt lamps at half voltage need be of the same frame size as a "regular" transformer of 16.25% of 5 KW. That is to say, any 800 watt two-coil transformer frame rewound

as an auto-transformer should operate 5 KW of lamps at half voltage with no more heating than it had when a two coil 800 watt transformer.

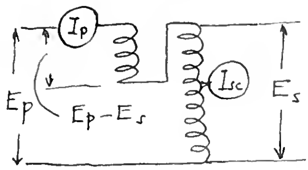
Reference to the Tungsten lamp characteristic curves for other voltages shows similar results; i.e. that the "equivalent transformer" rating of the device will vary from zero at full voltage (no dimming) up to a maximum of about 17.5% of the lamp load rating at 20% of candle power and then drop off to 11 percent at the 1 to 1/4 ratio that barely causes the lamps to glow.

GENERAL THEORY

The curves on drawing No. 673 show these relations. As the principle reference or variable is the "Candle Power of Lamps" it is best to refer all factors as candle power is altered to their value as a percent of their value at full candle power.

The curves R_s, I_s, and "volts at lamps", representing resistance, current and voltage at lamps with variable candle power are taken from the Mazda Lamp Engineering Data Book and provide the starting point. E_s or "volts in transformer" is slightly higher due to resistance in leads. Secondary watts E_s I_s is directly plotted and as the primary voltage is constant this curve will also represent percentage variation of primary current, neglecting slight internal losses. The watts transformed which represents the

electro magnetic work done in the device and is a measure of its weight and cost can now be obtained by first determining the current in the secondary part of the coil from the following relation:



$$(E_p - E_s) I_p = E_s I_{sc}$$

or

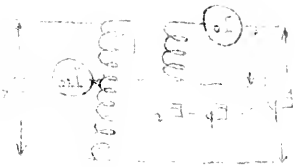
$$I_{sc} = \left(\frac{E_p}{E_s} - 1 \right) I_p$$

This value I_{sc} is shown on the chart and by multiplying by E_s the true electro-magnetic transformation in the device is obtained. This is plotted on a double sized scale of abscissa to show its detail.

A study of the internal currents at the various ratios of transformation show also that considerable economy of copper may be had by dividing the coil into three sections in large auto-transformers and in two sections in smaller ones.

The proof of the principle that the addition of resistance leads amounts to the same thing as an intermediate point of dimming is easily shown by applying Kerchoff's laws to the branch circuit. Assume in the diagram below for example the conditions at point 18 and 19 of the transformer whose design is shown in the drawing.

When the brush is on point 18 the actual volts will be the



generated volts less the drop in resistance lead or 79 - 24X.07 or 77.3 volts. Wheh on point 19 it will be 76 - 23X..08 or 74.1 volts.

When the two points are short circuited, if we let X equal amperes through ACB (See diagram) and Y equal amperes through AB, then

$x + y = 23.5$ let us say

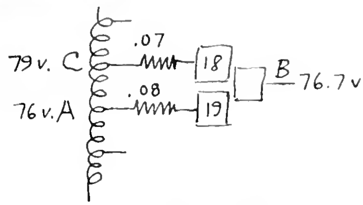
(See chart for value of I_s

$-3 + .07x = .08y$

equalizing volt drop

whence $y = -9.1$ amps.

$x = 32.6$ amps.



and the volts at terminal is 76.7

This is not half way between but it is enough of a jump to materially improve the action of the device. The relative position that this figure has to the volts at adjacent points cannot be altered much by wide variations of resistance in the leads provided their relative value is the same.

COMPARISON OF ECONOMY OF OPERATION WITH THAT OF RESISTANCE DIMMING.

The saving in power due to the use of this device for the purpose of dimming as compared with the usual method of dimming with rexistance plates is easily read directly from the characteristic curve. Thus the curve of Secondary Amp. variation I_s is also the curve of variation of total power

input at the various candle powers if resistance dimming be used. The curve of power input when induction device is used is that shown on the chart as "Secondary Watts." Therefore the saving of this device as compared with resistance dimming is measured by the horizontal distance between the curves of I_s and $E_s I_s$ and may be directly read from the curve sheet as a percent of the full candle power wattage of the bank of lamps, as for instance:

WATTS LOST IN DIMMING BY THE RESISTANCE METHOD AS A PERCENTAGE OF TOTAL WATTAGE OF THE LAMPS AT FULL CANDLE POWER.

This amount is saved in device under discussion.

Candle Power of Lamps	Percent of full candle power wattage of lamp bank.
100%	0 %
80	5
60	11
40	17.5
20	28
10	33
0 (barely glow)	35

The above factors give the quickest way of determining the watts saved by the device under discussion for any condition of candle power of the lamps. It does not however show the true percentage of amount saved of the proposed device as compared with resistance dimming. The latter percentage is of course, for any given candle power

$$\frac{\text{Watts used by resistance method} - \text{Watts used by induction method}}{\text{Watts used by resistance method}} \times 100$$

which is given in table below:

PERCENTAGE OF SAVING OF DEVICE UNDER DISCUSSION AS COMPARED WITH RESISTANCE METHOD

Candle Power of Lamps		Percent power saved
100%		0
80%		5.4%
60		12.0
40		20.4
20		36.2
10		49.0
0	(barely glow)	70.0

Now in the actual operation of a dimming bank in a theatre the time that the handles are set to produce 60 to 80 per cent of candle power is very small indeed, being only in the transition down to the usual "Dim" of a darkened stage and the majority of the time that the dimming handles are in use at all will find them somewhere in the lower ranges of candle power. The saving at these ranges is seen from the table to be quite marked.

All of the above refer to power savings and do not show energy saving for a cycle of the show. The latter is more difficult to estimate, and in fact cannot be done, of course, unless the time-dim requirements for the show are known. There is one phase of it however that bears invest-

igation at this point and that is to determine under what condition it is best to go to the complication on the control device of having an auxiliary arm that will cut out the auto-transformer from the circuit when full voltage is desired thus eliminating the open circuit core losses of the device.

For instance, if the device is accross the line during all the time that the bank of lamps is on, even though steady burning at full voltage, the energy loss in the device will be the kilowatt hours lost in the core for the time it was connected. This energy of course must be subtracted from the energy saved by the device during the time bank is dimmed.

In the design of auto-transformer shown on the drawing, which is typical of what may be expected of devices of this character the core loss at 60 cycles is at the rate of 14 watts, or 14 watt hrs. per hr. At 20% candle power 14 watt hrs. is saved as compared with resistance dimming in 55 seconds. We therefore conclude that the point at which the saving equals the losses in the device will be reached if the dimmer is in use to produce 20% full candle power 55/3600 of the time; i.e. 1.5% of the time., The conclusion as to whether the expense of an extra arm on the control device is justified will therefore depend upon the character of the time-dim curve, and the reasoning for determining

the answer in any particular case is suggested sufficiently in the above. For the usual photoplay house or theatre the economics of the proposition will show that such an additional arm to eliminate core losses when the lamp bank is burning full voltage is justified as it will save its cost in about a year, but that for lodges, schools and places where the productions are intermittent it is a needless and unecomomic addition. We therefore conclude that in the manufacture of a line of dimming equipment embodying the device under discussion an auxiliary arm to cut out the auto-transformer when lamps are at full voltage will be included on all "theatre type" units but we will eliminate the same from all "lodge type" units - to use the parlance of the resistance dimmer catalogs.

COMPARISON OF FIRST COST OF DIMMING SYSTEM USING THE DEVICE UNDER DISCUSSION WITH COST OF RESISTANCE DIMMING.

In considering this matter we are under the handicap of having to discuss the expected cost of manufacture of the device proposed with the selling price to switchboard manufacturers of resistance dimming equipment. The correct method is of course to compare the cost to make the new device with the cost to make the old. If the same sub division of control plates and flexibility is insisted upon with the new system as with the old (and we will show later that this is not at all an essential premise) the best way to show relative costs is to take a typical specification

for a theatre and compare the two. For purpose of discussion let us take the case of the Indiana Theatre at Terra Haute, Indiana which has a complete schedule of dimming apparatus referred to in Crofts "Lighting Circuits and Switches" First Ed. pp 436-437.

The cost of operating handles and interlocking shafts for the two systems may be said to be the same with the advantage if any in favor of the induction system. This is for the reason that the largest standard resistance theatre plate is 30 amps, and for dimming say the white circuit in the footlight 9000 watt three wire, the resistance system will require four plates and the induction system only two plates. The cost of tying these plates mechanically together is therefore less in the induction system, also less support and room on the board is required.
The cost to a switchboard manufacturer of the plates only for the resistance dimming system of the Indiana Theatre was probably about $2060 the same comprising 59 plates.
In the induction system we would tie the proscenium strips to the foots as when one is dimmed the other is dimmed, and have a disconnect between them on the low voltage side and the job be taken care of with the following equipment:

		amp	2	wire	control	plates	each	with	one		
2	60	"	"	"	"	"	"	"	"	6.6	KVA Coil
12	30	"	"	"	"	"	"	"	"	3.3	" "
3	30	"	3	"	"	"	"	"	two	3.3	" "
7	60	"	"	"	"	"	"	"	"	6.6	

The number of controller plates is reduced from 59 to 34 as compared with resistance system.

As to the cost of these devices a survey with a small transformer manufacturer and a switchboard manufacturer seems to indicate that auto-transformer coils with 50 taps, providing 100 steps of dimming may be had for prices as follows when on a manufacturing basis of at least a hundred at a time:

3.3	KVA	Coils	complete	in	case	$14.50 each
6.6	"	"	"	"	"	$19.50 each
11.0	"	"	"	"	"	$25.50 each

The cost of 50 point control plates similar to illustration but with auxiliary cut out arm, providing 100 steps of dimming is estimated on the same production basis to be as follows:

30 amp plates $20.00 each

60 amp plates $30.00 each. 3 wire controllers double price

100 amp plates $50.00 each.

The above prices are selling prices to an assembler therefore they may be presumed to contain a factory overhead and small profit.

Applying the above estimates to the Indiana Theatre job we have for apparatus equivalent to that furnished by the resistance dimmer manufacturer for $2060.00, a cost of $1413.00, or a saving of $547.00 in first cost on the Indiana Theatre job.

It must be recognized that in the above we are comparing the costs to a switchboard manufacturer. The chances are that the resistance dimmer manufacturers have figured in their prices considerably more overhead and profit than the small manufacturer who would make auto-transformers and control plates on sub-contract so that if absolute costs, labor, and material were compared the advantage shown by induction apparatus might be wiped out.

Even so the comparison is quite favorable indeed as it is apparent from the savings to be expected in operation the induction apparatus should command a much higher price in the market.

It will be recalled that the preceding comparison is based upon equal flexibility. As a matter of fact, however, the flexibility of stage lighting is in some respects merely an after effect of the great sub-division in switching necessary due to the fact that dimmer plates cannot be made larger than 30 amps. under ordinary space limitations (The Ward Leonard Company has just announced its largest continuous dimmer plate is reduced to 27 amps.) and also that in the resistance system each plate must have a rating exactly corresponding to the rating of the load to which it is connected. In the induction system proposed no such limitation exists as a 100 amp. control plate and 11 KVA coil will dim one 50 watt lamp as efficiently and with the same gradation of con-

trol as it will care for 11,000 watts. It will thus be seen that considerable simplification and consolidation may be permitted and at great savings of cost by using centralized induction units and disconnecting switches on the low voltage side. For instance in the Indiana Theatre job previously considered, there is no good reason why all the amber house lights should not be on one three wire control plate and disconnecting switches placed on the low voltage side to eliminate one or all of balustrades, and oriole grills. It is inconceivable that there would be any practical reason for wanting to dim the balustrade ambers "up" while dimming the oriole grill ambers "down", or to dim either at a different rate than the amber side coves. What is wanted is to be able to dim,any combination of the three up or down and to eliminate one or two from the three at will. This is easy to do by the proposed device.

Whereas the Indiana Theatre schedule shows only a front and back border which probably should be separated so one can be dimmed "up" while one is dimmed "down" such a dondition would be simplified in a larger stage with 4 to 6 borders. For instance Border No. one could have one control equipment. Border No. 2 and No. 3 could be consolidated on one control plate with disconnecting switches on the low voltage side. Similarly Border No. 4 and 5 could be consolidated on one control plate. Such a plan would provide all the flexibility that one has reason to expect.

In the case of the pockets and cradle spot dimmers a most important condition must be examined. The dimmer on the board is arranged to carry the maximum load that it is expected the pockets will ever have connected to them at one time. If it is desired to obtain accurate dimming from a pocket in only one or two places such as for a couple of 500 watt spots it is customary practice to do what is called "load up the pockets" by inserting a battery of large Olivette lights in the other pockets and turning their face to the wall thus causing an outright waste of the electricity they use. All this would be avoided by the induction apparatus. The chances are that the most fertile field for the sale of the new device would be found in replacement of existing resistance dimmers on the pocket and cradle spot panels of existing switchboards. This would be so obvious that the trade should take to it readily and it would be a good preliminary to campaigning for general replacement of the entire board.

CONSOLIDATION OF SYSTEM OF CONTROLLER PLATES
TO ONE OR MORE AUTO-TRANSFORMERS.

It is to be observed that there is nothing to prevent more than one controller plat being connected to a single auto transformer. For instance in a theatre there may be only four such auto transformers, two for the stage lighting and two for the house lighting, each one connected to opposite sides of a three wire system. If these are of suffi-

cient size they will handle all the controller plates. There is, however, an objection to this plan in that if one transfomer should burn-out whole sections of the theatre would be inoperative; furthermore as the various sections of the coils in the auto-transformer were short circuited by the various controller plate arms bridging adjacent contacts there would be a variation of voltage on everything connected to that auto-transformer. To take an extreme case of a 50 point transformer feeding 50 controller plates, each controller might be bridging a different coil from any of the others. In such case the current in the winding would be so great that the supply would be so heavily drawn upon to maintain any semblance of voltage that primary fuses would certainly blow.

DISCUSSION OF NUMBER POINTS OR STEPS OF DIMMING.

Resistance dimmers have an arrangement of steps the number of which is dictated by two considerations; the number of candle power steps necessary to prevent jumping, and the limitations of the area of a radiating disk housing the resistance coil. For some time the writer has suspected that there is no real reason for having as many steps of dimming as provided by the commercial resistance dimmers from the standpoint of candle power jumps. Tests made on resistance dimmer plates show the arrangement to be based upon substantially equal variations of candle power from step to step.

It would appear in theory that the number could be reduced by having each step bear a definite ratio to the candle power of the step adjacent; that is, use geometric progression instead of arithmetic. This would seem to be expected by a consideration of the physiology of the sensation of jumping of lighting. It would appear to be true that within the ranges of normal illumination with no glare or eye strain if the eye could detect a variation of 5% in illumination from a normal and could not detect a 4% variation from a normal, then regardless of the absolute illumination the same ratio would prevail. Experiment seems to indicate there is some truth in this and it is well known that the jumping sensation in dimming of existing resistance type dimmers is more apparent at low dimming than near the top. This would be caused by the arithmetic progression of candle power, thus if the steps are arranged in 100 equal parts of candle power the progression from step 3 to 4 is an increase of 33% of what it was at point 3 causing a distinct sensation of jump, whereas from 98 to 99 the variation is 1% or drawn too fine.

The transformer design submitted in connection herewith has arithmetic progression by equal steps from 100% to 20% candle power, thence by steps of half as great to zero candle power. Additional devices built show an improvement if the steps are divided geometrically down to about 10% of candle power thence arithmetically for the balance to avoid the

number of steps becoming infinite.

It is also found that the number of steps necessary for white dimming is not the same as needed for colors. Blue dimming can take place with half the steps of white dimming due to the tremendous absorbtion of blue color screens. Red is so colorful that it seems to need the same number of steps as white, but a great saving can be made in controller manufacturing cost if the steps for the blues are reduced one half.

X CLAIMS TO ORIGINALITY

In the preceding discussion it is evident that claims for apparatus as well as a complete combination or system can be made embodying the entire use of the device for dimming lamps or regulating voltage on other devices that have similar approximately constant resistances. The auto-transformer is old, but its use in such a combination involving resistance in the leads, the auxiliary cut out arm, and on a lamp bank is new. Analyzing the situation the writer would claim to be new as follows:-

(1) In an auto transformer or transformer a multiplicity of taps each giving different terminal voltages with resistance inserted in each lead of such value as to substantially limit the current in the part of coil of transformer or auto-trans-

former between any two such adjacent taps to such amount as will not cause undue heating or humming in said coil,

(3) In an auto transformer or transformer a multiplicity of taps each giving different terminal voltages with resistance inserted in each load of such value that errors in winding transformer to produce a predetermined terminal voltage may be corrected by alteration of resistance in said tap.

(4) In an auto-transformer or transformer a multiplicity of taps each giving different terminal voltage with resistance inserted in each lead of such value that when any two such adjacent taps are connected to one or more switch contacts or arms the voltage at any such contact will be intermediate between the voltage at each adjacent tap when said contact is not connected to said adjacent taps.

(5) An autoptransformer or transformer having a multiplicity of taps each one with or without resistance in leads, one or more controller plate to connect leads therewith to each tap successively each said load to be substantially non-inductive and having its internal resistance from the nature thereof vary within a range of from 55% of its maximum value when connected with any said tap to said maximum value, as said loads are connected successively to said taps.

(6) An auto transformer or transformer having a multiplicity of taps each one with or without resistance in leads the

arrangement and connection of said taps being such that the terminal voltage will progress successively from each tap to the one adjacent thereto so that the candle power of a lamp bank connected to such device will vary in substantially equal steps of candle power from maximum to minimum or vice versa as connection is made successively from tap to tap singly and individually even though the intermediate step of candle power when the connecting device is on two adjacent points of the controller is unequal.

(7) An auto-transformer or transformer having a multiplicity of taps each one with or without resistance in leads the arrangement and connection of said taps being such that the terminal voltage will progress successively from each tap to the one adjacent thereto so that the candle power of a lamp bank connected to such device will vary in substantially steps of geometric progression of candle power from maximum to minimum or vice versa as connection is made successively from tap to tap singly and individually even though the intermediate step of candle power when the connecting device is on two adjacent points of the controller may not so vary.

(8) An auto transformer or transformer having a multiplicity of taps each one with or without resistance in leads, one or more controller plates to connect loads, therewith to each tap successively, a switch interlocked with the operating of mechanism of said controller plates so arranged that said auto-transformer or transformer may be connected to or disconnected from supply circuit without any disconnection of the several loads from the supply circuit.

APPENDIX A

Watts Lost in Leads and Overall Efficiency

In the course of development of actual apparatus embodying the preceding principles it was apparent that some calculating was necessary for proper proportioning of resistance in leads so that the watts dissipated therein, particularly at certain steps, would avoid operating at a temperature higher than safe for the resistance material.

The curve sheet attached shows details of the arrangement of steps on a commercial line of plates, and the formula for maximum watts dissipated in leads is developed and shown in the lower right corner thereof. The table shows the determining factors for the design of the resistances; viz. ohms and watts dissipated. Any alloy used for the coils has characteristics obtainable from the manufacturer as to watts that may be radiated per foot for the various sizes of wire.

It is a two to one chance that the operator will keep the controller arm bridging two adjacent points so this loss in leads due to circulating current is the main factor in calculating the efficiency of the device. At less than 4% candle power it is the worst with a loss of 3.2% of full voltage lamp bank rating or 13% of the power used by the lamps at 5% of full candle power. At half candle power it is 9/10 of 1% of full voltage lamp bank rating or 1.25% of power used by lamps at that candle power.

The curve also shows the arrangement of steps by geometric progression with arithmetic progression in the lower part.

A

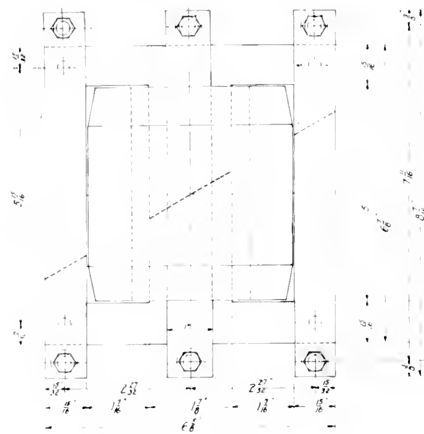
APPENDIX B

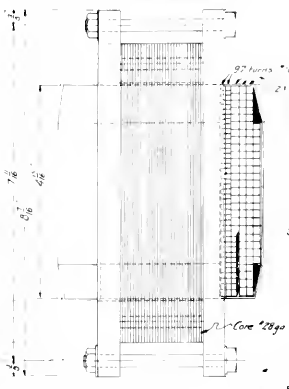
USE OF INDUCTIVE REACTANCE IN PLACE OF RESISTANCE.

The control of the short circuit current may also be had by causing each lead to loop around an iron core either inside or outside of the transformer shell, thus considerably simplifying the control mechanism. A range of inductance from .07 to .28 mil henrys for the 30 amp. unit for the various leads is satisfactory with half this for the 60 amp. unit and three-tenths of same for the 100 amp. unit. Calculation will show this may be obtained by two or three turns around a core of iron wire and one core will do for all of the leads which can be wound axially thereon. This core should preferably be placed inside the transformer case so it can be impregnated to avoid humming when load current causes it to be magnetised.

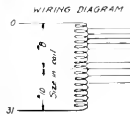
We thus arrive by somewhat devious routing to an exceedingly simple article, but it is typical of the inventive process. Each of the claims to originality, except No. 4, should be modified to read "reactance or resistance" where it now reads "resistance", and the construction of this inductive reactance as an integral part of the transformer, with one core doing for all the leads, should be included separately. It is also possible to combine the two magnetomotive circuits of the auto transformer and the control reactances into one shell type stamping.

For theatre stage use where the intermediate step of voltage, when contacts are bridged, is important, as more perfectly graduating the candle power, the resistance method of controlling the short circuit current should be adhered to, as this effect is not had if inductance be used.





WIRING DIAGRAM

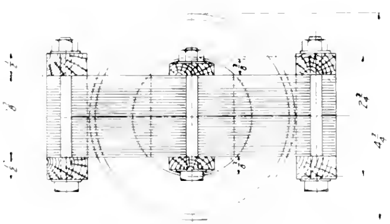


Leads 0 to 15 and 31 #8 S.B. white finish
Leads 16 to 30 #10 S.B.
All leads ft. long

No. of Wire	Tap No.	Turns	Feet	Mean length of Turn	Ohms each lead
10	31	0	0		
	30	66	47.5	.9	0.21
	29	83	63.7	83	20
	28	97	75.7	85	7
8	27	106	83.2	88	13
	26	114	91.0		09
	25	120	96.3		07
	24	125	100.7		06
	23	131	105.1		06
	22	136	109.9		06
	21	141	114.7		06
	20	145	118.6		.07
	19	152	125.3		08
	18	158	131.0		07
	17	164	136.8		06
	16	168	141	1.05	04
	15	172	145.2		03
	14	176	149.4		03
	13	180	153.6		03
	12	183	156.7		03
	11	186	159.9		03
	10	189	163.0		03
	9	193	167.2		03
	8	196	170.7	1.15	03
	7	199	174.1		03
	6	202	177.6		03
	5	205	181.0		03
	4	201	184.5		03
	3	211	187.9		03
	2	214	191.4		02
	1	217	194.8		.01
	0	220	198.3		0

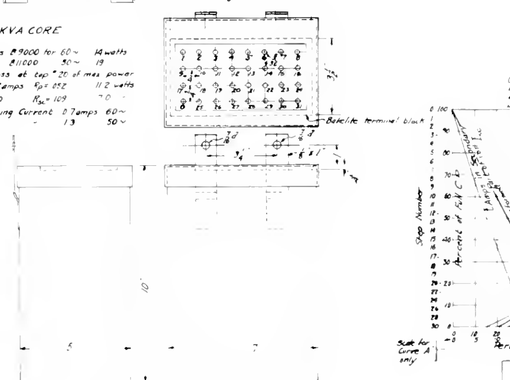
WINDING TABLE

Note Last column refers to resistance on control device to permit smooth dimming by short circuiting each section through contact brush

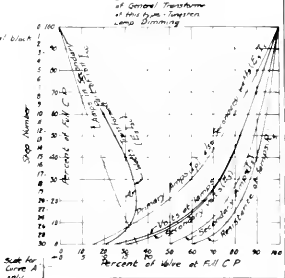


330 KVA CORE

Core Loss B 9000 for 60~ 14 watts
B 11000 50~ 19
Copper Loss at tap #20 of max power
I_p = 14.7 amps R_p = .052 11.2 watts
I_{sc} = 8.0 R_{sc} = .109 7.0
Magnetizing Current 0.7 amps 60~
1.3 50~

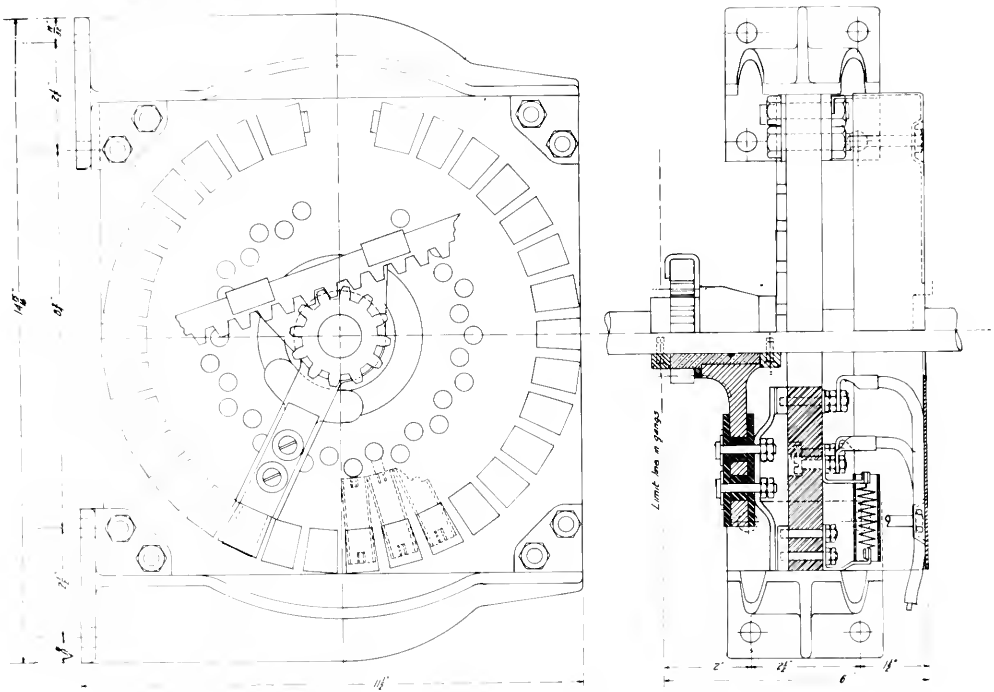


Case of #6 ga black iron weld and fill with wax
Scale ½ size

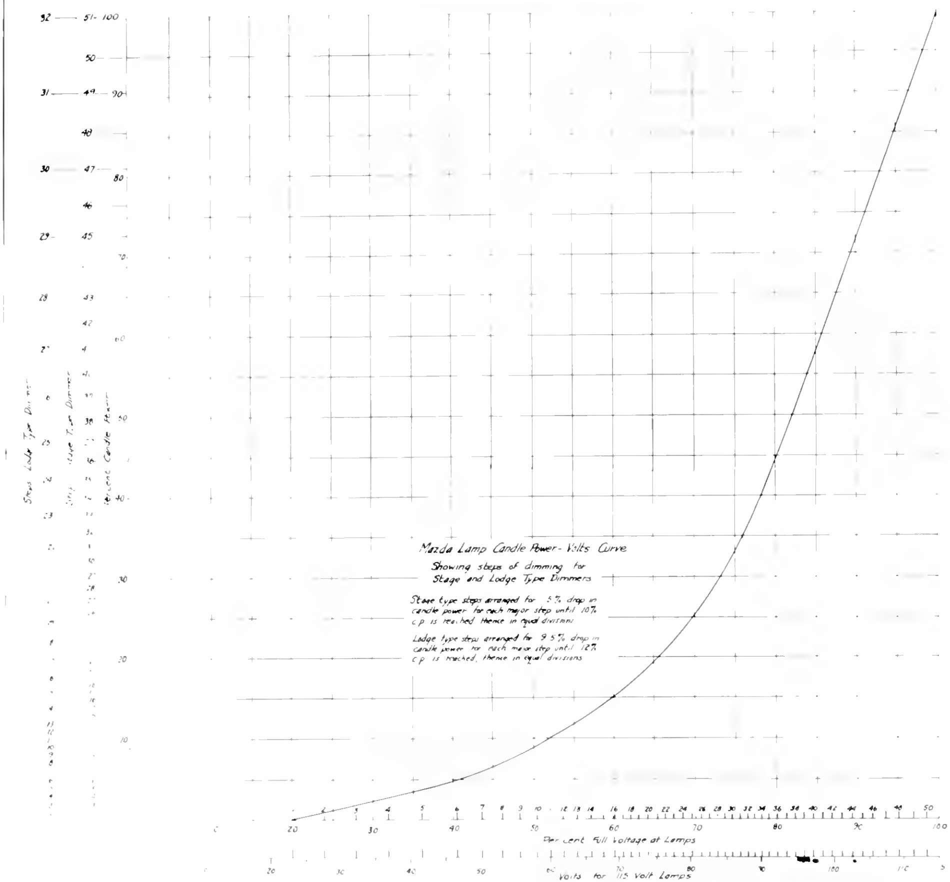


Autotransformer Designed for Induction Dimming of 30 amp 110v Tungsten Lamps
Also General Characteristic curves

T. W. Simpson Sep 30 1925
No. 673
San Francisco



Control for Induction
Dimmer
Capacity 3000 watts
of Tungsten lamps
T W Simpson Sep 30 1925
No 672
San Francisco



Proportions and Design Factors (Heat to be dissipated in Resistance in leads to prevent overheating of short circuited coil

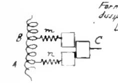
For Stage Dimmers - 51 points 102 steps

30 Amp Size		60 Amp Size		100 Amp Size		
Ohms in each lead	Max watts to be dissipated	Ohms in each lead	Max watts to be dissipated	Ohms in each lead	Max watts to be dissipated	
0.08	112	0.04	224	0.024	336	Leads 1 to 5
0.06	63	0.03	126	0.018	210	6 to 10
0.04	41	0.02	82	0.012	136	11 to 16
0.03	32	0.015	64	0.009	107	17 to 24
0.02	30	0.01	60	0.006	100	25 to 51

For Lodge Type Dimmers - 32 points 63 steps

0.08	112	0.04	224	Not made in 100 amp size
0.06	105	0.03	210	

Formula for watts to be dissipated in lead resistance



Let

x = amps in BC
y = amps in AC
m = ohms BC
n = ohms AC
a = volts generated in AB
b = amps at C (Obtain from resistance of lamp bank)

Then

$$x + y = b$$

$$-a + xm = yn$$

From which $y = -\frac{a-bm}{n+m}$ $x = b + \frac{a-bm}{n+m}$

x being the larger

Max watts dissipated $= m\left(b + \frac{a-bm}{n+m}\right)^2$

T. n. Simpson Oct 5 1925